DEVELOPMENT OF ASTM PRECISION BEARING GREASE GUIDE

Dr. In-Sik Rhee, U.S. Army Tank-Automotive Research, Development, and Engineering Center, Warren, MI

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ABSTRACT

Lubricating grease is one of important operational parameter in the rolling bearing applications. Specially, the selection of the lubricating grease for the precision bearing applications is very risky due to many other factors unique to any specific precision bearing environments. For this reason, ASTM F-34 Tribology Subcommittee did a study to develop a Precision Bearing Grease Selection Guide in joint effort with the Department of Defense (DoD). The purpose of this study was to take a broad spectrum of lubricating greases used in precision bearings, including instrument bearings, and do a comprehensive series of tests so their properties could be compared. This study is also meant to be a design guide for choosing lubricating greases for future precision bearing applications.

As a part of this study, thirty-eight lubricating greases, currently used in the precision bearings, were evaluated in comprehensive series of laboratory tests. Vital recommendations were then made based on a collective effort by members of this community, who span the spectrum from bearing manufacturers, original equipment manufactures (OEMs), grease manufacturers and suppliers, procurement specialists, quality assurance representatives (QARs) from DoD, and end users both inside and outside DoD. This study has been completed within ASTM F-34 Tribology Subcommittee and published as a new ASTM Standard Guide, F- 2489. This paper presents the results of the grease testing program, grease selection guide, and recommendations.

INTRODUCTION

The number of lubricating greases used in Precision Rolling Element Bearings (PREB) increased dramatically from the early 1940s to today. In the beginning of this period, petroleum products were the only widely available base stocks. Later, synthetic base oils became available. They included synthetic hydrocarbons, esters, silicones, multiply alkylated cyclopentanes (MAC, tradename: Pennzane) and fluorinated materials, including perfluorinated ethers and the fluorosilicones. This broad spectrum of lubricant choices has led to the use of a large number of different lubricants in PREB applications. The U.S. Department of Defense, as a user of many precision rolling element bearings including instrument bearings, has also seen a significant increase in the logistics effort required to support the procurement and distribution of these items. In addition, as time has passed, some of the greases used in certain PREB are no longer available or require improved performances due to advanced bearing technology/requirements. This implies that replacement lubricating greases must be found, especially in this era of extending the lifetime of DoD assets, with the consequent and unprojected demand for sources

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of replacement[1]. For this reason, a precision bearing grease testing program was initiated by a joint effort between DoD and ASTM F-34 Committee.

The purpose of this guide was to report on the testing, discuss and compare properties, and to provide guidelines for the choice, of lubricating greases for PREB. The PREB are, for the purposes of this guide, meant to include bearings of ABEC 5 or above quality[2] . This guide limits its scope to lubricating greases used in PREB. One of the primary goals of this study was to take a broad spectrum of lubricating greases used in PREB and do a comprehensive series of tests in order to compare their properties and, if necessary, identify potential replacement greases. This study is also meant to be a design guide for choosing lubricating greases for current and future PREB applications. This guide represents a collective effort of many members of this community who span the spectrum from bearing manufacturers, original equipment manufactures (OEMs), grease manufacturers and suppliers, procurement specialists, and quality assurance representatives (QARs) from DoD and end users both inside and outside DoD.

This guide does not cover other types of greases, such as industrial greases or automotive general purpose greases. There are two areas where this guide should have the greatest impact: (*1*) when lubricating grease is being chosen for a new bearing application and (*2*) when grease for a bearing has to be replaced, e.g., original grease specified can no longer be obtained. The report contains a series of tests on a wide variety of greases, commonly used in bearing applications, to allow comparisons of those properties considered to be the most important when making a choice of lubricating grease. Each test was performed by a laboratory to improve the test precision. This guide contains a listing of the properties of greases by base oil type, that is, ester, perfluoropolyether (PFPE), polyalphaolefin (PAO), and so forth. This organization is necessary because the operational requirements in a particular bearing application may limit the choice of grease to a particular base oil type and thickener due to its temperature stability, viscosity index or temperature-vapor pressure characteristics, etc. The guide furthermore recommends replacement greases for those greases tested that are no longer available. The guide also includes a glossary of terms used in describing/discussing the lubrication of precision and instrument bearings.

Characteristics of Precision Bearing Greases

(1) Precision bearing grease contains base oil to which a thickener has been added to prevent oil migration from the lubrication site and various additives to improve its operating performance. Currently, many technical articles often designate types of lubricating greases based on their thickeners. However, the operative properties of precision bearing greases depend on the combination of base oil, thickener and additive formulation. This guide distinguishes lubricating greases by their base oil types.

(2) Cleanliness is critical to bearing life. Even micron size contamination can impact bearing life/performance and result in bearing failure. Clean greases or Ultra-filtered greases that exclude particles above a predetermined micron size can prevent wear on precision bearings and extend the bearing life[3].

(3) The types of thickener material and its quantity are vitally important to obtain a stable grease structure and its physical properties. The improper ratio of thickener to base oil has a profound impact on grease's consistency, mechanical stability, excessive oil separation, and thermal-oxidation stability. These

physical and chemical properties of the grease tend to dictate the precision bearing's performance and its life.

(4) Thermal-oxidation stability is generally observed in the evaporation loss, dropping point, and oxidation stability tests. Typically, a low evaporation loss and excellent oxidation stability are required for precision bearing greases in order to have a long service life.

(5) Tribological properties are some of the important operational parameters in precision bearing greases. Most precision bearing greases often use anti-wear additives to improve their wear prevention properties. Some precision bearing greases incorporate EP additives to improve a load carrying capacity, but this property may not be required in all precision bearing applications.

(6) A wide operational temperature range is desired for the precision bearing greases. This property should be determined based on dropping point test and low temperature characterization at actual operational temperatures. Further testing in high temperature test rigs should be done to validate bearing-lubricant performance at operational temperatures.

(7) Channeling capability of lubricating grease is a critical property for PREB lubrication. It assesses the tendency of the grease to keep oil inside of the precision bearing. This capability tends to form a channel by working down of lubricating grease in a precision bearing, leaving shoulders of unworked grease which serves as a seal and oil reservoir[4].

(8) Corrosion prevention and good water stability (minimal change in consistency under wet conditions) are also important properties to prevent rust on bearing surfaces and to preserve grease consistency.

(9) Apparent dynamic viscosity tends to indicate the usable temperature range of lubricating grease for high speed precision bearing applications.

(10) Long grease life is desired in precision bearing applications. Most precision bearings are not re-lubricated during their lifetime. Furthermore, the grease life is also dependent on the operational temperature.

(11) A high level of noise generated from a precision bearing is usually caused by surface defects or damage of the anti-friction components (balls, races), due to the solid or semi-solid particles present in lubricating greases. Quiet greases, formulated with few very small particulates or filtered to remove the particulates, are typically required for precision bearing applications.

(12) Seal compatibility may vary with each lubricating grease. The type of material used in seals will determine which lubricating greases can be used in a particular PREB. Compatibility issues can be resolved by previous experience with PREB or by the ASTM D 4289 test method with actual seal materials (i.e. careful consideration must be given to assure compatibility between the grease and the bearing seal, shield and/or retainer materials).

(13) The base oils, thickeners, and additives dictate precision bearing grease performances. The properties of many based oils used in the precision bearings can be found in the ASTM F-2161 Guide[5].

TEST DETAIL

All thirty-eight (38) commercial greases selected for evaluation in this program are listed in Table 1. This table presents the classification of base oils, thickener types, grease manufacturers, and military specification products evaluated in this program. Most of these greases are currently used in precision bearing applications and all of these samples were selected by ASTM F-34 members, grease manufacturers, and users. Table 2 lists the test protocol for this study and covers the test methods, their test conditions, and the testing laboratories. This test protocol covers the essential requirements identified for precision bearing greases. The performance requirements of these greases are very unique. They are dictated by the performance expectations of precision bearings including high speed, low noise, extended life, and no contamination of surrounding components by the bearing's lubricant system. To increase the reliability of test data, all tests were performed by a DoD laboratory and three independent testing laboratories. Most tests were performed by U.S. Army Tank–Automotive Research, Development and Engineering Center (TARDEC) and some of them were tested in three independent laboratories, and the Naval Research Laboratory (NRL) monitored the results. This continuity of testing should form a solid basis for comparing the properties of the multitude of lubricating greases tested by avoiding some of the variability introduced when greases are tested by different laboratories using different or even the "same" procedures. Due to the ASTM Trade name policy, the greases samples were identified as their codes in this paper, but their actual trade names are listed in ASTM Research Report F34-1000.

Table1. Classification of Tested Greases

Code	Base oil	Thickener	Manufacturer	Color	Military Standard
G-1	Mineral	Calcium	Shell	Dark orange	MIL-G-25537
G-2	Mineral/PAO/Ester	Calcium Complex	Kluber	Almond	No
G-3	Silicone	Lithium	Dow Corning	Dark pink	MIL-G-15719A
G-4	Silicone	Lithium	Dow Corning	Light pink	No
G-5	Silicone	PTFE	Kluber	White	No
G-6	Ester	Clay	Shell	Light brown	MIL-G-25760
G-7	Ester	Clay	Shell	Dark grey	MIL-G-21164
G-8	Ester	Polyurea	Kluber	Tan	No
G-9	Ester/PAO	Polyurea	Kluber	Ivory	No
G-10	Ester/PAO	Lithium	Kluber	Ivory	No
G-11	Ester/PFPE	Polyurea	Kluber	Tan	No
G-12	Ester	Clay	Shell	Light brown	MIL-PRF-23827, Type II
G-13	Ester/PAO	Lithium Special	Lubcon	Beige	No
G-14	Ester/PAO	Lithium Special	Lubcon	Beige	No
G-15	Ester	Lithium complex	Nye	Ivory	No
G-16	Ester	Lithium complex	Nye	Almond	No
G-17	Ester	Lithium complex	Nye	Clear/almond	No
G-18	Ester	Lithium	Royal	Tan	MIL-PRF-23827
G-19	PAO	Polyurea	Shell	Tan	No
G-20	PAO	Lithium	Kluber	Cream	No

Code	Base oil	Thickener	Manufacturer	Color	Military Standard
G-21	PAO	Barium	Kluber	Off-white	No
G-22	PAO	Clay	Shell	Light brown	MIL-PRF-81322, DoD –G-24508
G-23	PAO/Ester	Lithium Complex	Shell	Green	MIL-PRF-23537, Type I
G-24	PAO/Mineral	Lithium Complex	Summit	Light brown	MIL-PRF-10924G
G-25	PAO	Lithium Complex	Nye	Cream	No
G-26	PAO	Lithium Complex	Nye	Cream	No
G-27	PFPE, Branched	PTFE	Dupont	White	MIL-G-27617, Type III
G-28	PFPE, Branched	PTFE	Dupont	White	MIL-G-27617, Type II
G-29	PFPE, Branched	PTFE	Dupont	White	No
G-30	PFPE	PTFE	Kluber	White	No
G-31	PFPE	PTFE	Nye	White	No
G-32	PFPE, Branched	PTFE	Dupont	White	MIL-G-27617,
G-33	PFPE, Linear	PTFE	Dupont	White	No
G-34	Ester	Lithium	Nye	Almond	SAE-AMS-G-81937
G-35	PFPE	PTFE	Aerospace Lubricant	Light yellow	MIL-PRF-83261
G-36	MAC (Pennzane)	Sodium Complex	Nye	Almond	No
G-37	PFPE, Linear	PTFE	Castrol	White	No
G-38	PFPE, Linear	PTFE	Castrol	Almond	No

Table 2. TEST PROTOCOL

Test	Method	Test Condition	Testing Laboratory	Evaluation
Dropping Point	ASTM D 2265	Standard	U.S. Army TARDEC	Measure the temperature at which the first drop of grease falls from the cup
Oil Separation (static)	ASTM D 1742	Standard	U.S. Army TARDEC	Measure the oil separation of grease under normal storage conditions
Oil Separation (Dynamic)	ASTM D 4425	40 C, 2hrs	U.S. Army TARDEC	Measure the oil separation of grease by a high speed centrifuge force
Work Penetration	ASTM D 217	Standard	U.S. Army TARDEC	Measure the consistency of the grease. Higher number indicates a soft grease
Copper Corrosion	ASTM D 4048	Standard	U.S. Army TARDEC	Measure corrosion on copper metal in comparison to the ASTM Copper Strip Corrosion Standards. The 1a and 1b ratings indicate no corrosion
Rust Preventive	ASTM D 1743	Standard	U.S. Army TARDEC	Determine the rust preventive properties of greases using grease lubricated tapered roller bearings stored under wet conditions (flash water). No corrosion is pass rating.
Water Stability	ASTM D217	Procedure A	U.S. Army TARDEC	Measure water stability of greases by using a full scale grease worker. The change in consistency after being subjected to water is a measure of the water stability of the grease. Small difference indicates better water stability.
Water Washout	ASTM D1264	Standard	Petro-Luburicants Testing Lab	Measure the percentage weight of grease washed out from a bearing at the test temperature.
Oxidation Stability	ASTM D 5483	Standard	U.S. Army TARDEC	Measure the oxidation induction time of grease under oxygen environments. A longer induction time indicates better oxidation stability.

Test	Method	Test Condition	Testing Laboratory	Evaluation
Evaporation Loss	ASTM D 972	Standard	U.S. Army TARDEC	Measure the evaporation loss of greases at 99 C.
High temperature Evaporation Loss @180 C	ASTM E 1131 (TGA)	1 hr	U.S. Army TARDEC	Measure the evaporation loss of grease at 180 C.
Channeling Ability	ASTM D 4693 (Bearing Test)	Visual check after bearing test	U.S. Army TARDEC	Determine channeling capability of grease in a lubricated tapered roller bearing.
Apparent Dynamic Viscosity	TA Rheometer	At 25 °C	ICI Paints Strongsville Research Center	Measure apparent dynamic viscosity of a grease at 25 C
Wet Shell Roll Stability	ASTM D	Procedure B	U.S. Army TARDEC	Measure water stability of greases using a roll stability test apparatus, small sample required. . The difference in cone penetration before and after being worked in the presence of water is a measure of the effect of water on the grease. Small difference indicates better water stability.
Work Stability	ASTM D 217	Standard	U.S. Army TARDEC	Determine the work stability using a grease worker. The difference between the cone penetration before and after working is a measure of the worked stability of the grease. Small difference indicates better worked stability.
Roll Stability	ASTM D 1831	Standard	U.S. Army TARDEC	Determine the roll stability of grease. The difference between the cone penetration before and after rolling is a measure of the roll stability of the grease. Small difference indicates better roll stability.
Four Ball Wear Test	ASTM D 2266	Standard	U.S. Army TARDEC	Determine the wear preventive characteristics of greases in sliding- steel-on-steel applications. Measure the diameters of wear scars after the test. A small diameter indicates less wear.
Four Ball EP Test	ASTM D 2596	Standard	U.S. Army TARDEC	Determine the load-carrying properties of greases. It measures Load –wear index (LWI). A high LWI number indicates a better load-carrying property.
Grease Life	ASTM D 3527	Standard	U.S. Army TARDEC	Measure grease life at the test temperature.
Low Temperature Torque	ASTM D 4693	Test temperatures, -20 C, -40 C, -54 C	U.S. Army TARDEC	Measure low temperature property of grease. It measures initial torque and running torque at 1 and 5 minutes. A lower number indicates a better low temperature property.
Rolling Bearing Noise	SKF Be-quite	Standard	SKF	Measure noise level using an acoustic instrument. The rakings are : very noisy (GNX)>noisy (GN1)>standard noise (GN2)>quite (GN3)>very quite(GN4)
Dirt Count	FTM 3005	Standard	U.S. Army TARDEC	Measure the cleanness of greases. Zero indicates no dirt contamination.

TEST RESULTS AND DISCUSSIONS

The test results of the 38 precision bearing grease selected are summarized in Tables 3-5. Each grease tested was assigned a code to mask their source to mitigate any potential bias in the testing results. Each grease was tested for dropping point, consistency, water and work stability, oxidation stability, oil separation, evaporation loss, wear, EP properties, corrosion prevention, low temperature characteristics, cleanliness, apparent viscosity, grease noise, and grease life. Compatibility testing with elastomers incorporated into PREB and their environments were not done due to the large number of combinations that would require testing to span the potential mixes of greases and elastomer components that might occur in bearing applications. It is recommended that the user verify grease/elastomer compatibility when needed.

In these tables, some of the data may not agree with those of manufacturers due to the variation of the test methods and their test apparatuses (i.e., noise test). All tests were performed by a government laboratory and three independent laboratories. No grease manufacturers performed any of these tests except for the base oil viscosities of greases.

Mineral oil base greases are, in general, not recommended as precision bearing greases. These greases may exhibit a high evaporation rate and excessive oil separation. Most of these greases also provide a short lubrication life and do not have good oxidation stability. They do not provide a wide temperature operation capability due to their chemical structure. In addition, their base oils vary from lot to lot depending upon the source of the crude oil used as feedstock and upon the exact chemical and physical processes used to refine the feedstock. The main advantage of mineral oils over synthetic oils is cost. In most PREB applications, the cost of the lubricant is usually a very small part of the overall cost of the bearing. Therefore, in most PREB applications, the differential cost of using a mineral oil versus synthetic oil based greases should not be a determining factor in the choice of lubricating greases.

Polyalphaolefins (PAO) based grease is widely available and is currently used in many PREB applications. PAO greases exhibit many of the physical properties that are required for the lubrication of PREB and have a long history of being used successfully in them. They are formulated with PAO oils, various thickeners, and additives. Their base stocks are very similar in chemical structure to paraffinic mineral oils yet have the advantage of being synthesized. Synthetically producing oil gives the manufacturer considerably more control over its chemical composition and thus controls the lot-to-lot variability and allows tailoring of properties to specific needs. Operational temperature ranges of PAO oil based greases are much wider than mineral oil based greases and their use is recommended for many PREB applications. However, some PAO based greases are not initially suited for the precision bearing applications. For example, they might require filtration processing to remove solid contamination prior to use.

Ester oil based grease is used in several PREB applications. The main advantage is that ester oil based greases have excellent lubricity and compatibility with a wide variety of lubricant additives and have a wide use temperature range. They have somewhat better low-temperature behavior and have a much longer lubrication life than PAO based greases in a high temperature operation. Many of these greases are currently used in PREB applications. Ester oil based greases are incompatible with some sealing materials such as Buna-n and care must be taken in selection of bearing seals when using them.

Silicone oil based greases have not been commonly used in PREB except in moderately high temperature applications where loads are low. They have outstanding oxidation stability at high temperature and exhibit low volatility. Their upper operational temperature usually depends on the stability of the thickener. The rheology of silicone greases is similar to that of the mineral oil based greases. The disadvantage of these greases is its poor lubricity and load carrying capacity. For this reason, the silicone greases normally are not used in ball bearing applications. Also, these greases may have a tendency to creep, possibly contaminating adjacent hardware, and leave fairly hard deposits on bearing parts. This problem may be an issue when considering silicone greases as a PREB lubricant.

Perfluoropolyethers (PFPE) based grease are normally thickened with polytetrafluoroethylene (PTFE). PFPE greases are chemically inert and stable with consistent performance in many conditions. They have high viscosity indexes (about 300), can be used at very low temperatures and have very low volatility. It has marginal lubricity under lightly loaded conditions and may not be acceptable in some of PREB applications. It can be subject to catalytic breakdown under highly loaded (extreme pressure) bearing operation conditions. PFPE greases can be very clean grease when subjected to filtration. They are long life greases in high temperature environments under moderate bearing loads. Currently, PFPE greases are used in many aerospace bearing applications. PEFE greases have a relatively high cost compared to most other synthetic greases. In the past, one problem with PFPE greases was the lack of soluble additives to provide corrosion and anti-wear protection. Today, there are a number of soluble additives available for these greases. However, experience with these additives is limited.

MAC based grease is a special type of grease formulated with a synthetic hydrocarbon based on a multiply alkylated cyclopentane (MAC) oil, sodium complex thickener, and additives. Currently, MAC based greases are used in aerospace applications. It is thermally stable and has low volatility. Its volatility is comparable with PFPE based greases. However, unlike the PFPE lubricants, conventional additives used in PAO and ester oil based greases can also be used in MAC greases to enhance their performance, but these additives can slightly increase the volatility of the grease in high vacuum applications. Because of its low volatility and improved lubricity, MAC based lubricants have replaced PFPE lubricants in several vacuum applications. As with the PFPE based greases, cost is high. Also, availability of MAC lubricants is currently limited due to its sole source supply.

TABLE 3. GREASE TEST DATA (A)

Code	**Dropping point (c)**	**Oil Separation (Dynamic) (%)**	**Worked Penetration (mm)**	**Copper Corrosion**	**Rust Preventive**	**Water Stability (1/10mm)**	**Wet Shell Roll Stability (1/10 mm)**	**Work Stability (1/10 mm)**	**Roll Stability (1/10 mm)**	**Four ball wear (mm)**	**Grease life (hrs)**
G-1	151	39	284	1a	Pass	62	53	47	37	0.36	27
G-2	215	24	284	1a	Pass	---	12	---	22	0.56	225
G-3	217	0.5	263	1b	Pass	-11	-8	40	3	2.20	295
G-4	218	3	285	1b	Pass	14	8	16	12	1.24	423
G-5	334	43	268	1b	Pass	---	-3	---	-4	2.27	354
G-6	321	45	295	1a	Pass	132	119	82	76	0.58	394
G-7	263	42	302	1a	Pass	25	37	59	49	0.49	231
G-8	286	5	259	1b	Pass	---	58	---	36	0.36	397
G-9	279	6	252	1a	Pass	---	69	---	45	0.40	300
G-10	338	24	266	1a	Pass	---	55	---	57	0.60	180

Code	Dropping point (c)	Oil Separation (Dynamic) (%)	Worked Penetration (mm)	Copper Corrosion	Rust Preventive	Water Stability (1/10mm)	Wet Shell Roll Stability (1/10 mm)	Work Stability (1/10 mm)	Roll Stability (1/10 mm)	Four ball wear (mm)	Grease life (hrs)
G-11	269	0.4	286	1a	Pass	---	21	---	10	0.44	371
G-12	282	45	321	1a	Pass	29	23	36	42	0.54	110
G-13	323	14	290	1b	Pass	---	11	---	4	0.47	90
G-14	279	13	249	1a	Pass	---	18	---	5	0.52	100
G-15	273	25	244	1b	Pass	---	83	---	25	0.49	240
G-16	195	32	318	3a	Pass	---	39	---	18	0.51	210
G-17	203	11	260	1b	Pass	---	113	---	47	0.85	170
G-18	187	34	271	1a	Pass	---	>162	41	24	0.91	100
G-19	213	5	274	1a	Pass	9	1	17	-8	0.48	400
G-20	194	57	257	1b	Pass	---	37	---	20	0.58	171
G-21	279	28	266	1b	Pass	---	7	---	3	0.48	120
G-22	310	47	290	1a	Pass	125	97	37	97	0.69	271
G-23	242	53	297	1a	Pass	7	7	12	10	0.52	140
G-24	256	13	281	1a	Pass	-2	-3	28	26	0.48	150
G-25	227	21	291	1b	Pass	---	38	---	22	0.35	49
G-26	225	8	213	2c	Pass	---	41	---	3	0.40	161
G-27	243	16	266	1b	Pass	---	11	---	19	0.83	397
G-28	191	33	260	1b	Pass	---	38	---	13	0.72	400
G-29	213	29	263	1b	Pass	---	42	---	22	1.00	450
G-30	293	13	275	1b	Pass	---	-4	---	30	0.87	365
G-31	217	31	256	1a	Pass	---	59	---	46	0.68	>500
G-32	221	33	303	1b	Pass	---	17	---	12	0.90	309
G-33	199	35	279	1a	Pass	---	-13	---	8	1.13	>500
G-34	207	19	218	1a	Pass	---	137	---	94	0.77	60
G-35	187	14	307	4a	Pass	---	21	---	34	1.41	>500
G-36	318	24	232	1b	Pass	---	80	---	70	0.37	>500
G-37	239	22	281	1b	Pass	---	10	---	1	0.77	>500
G-38	235	22	290	1b	Pass	---	1	---	6	0.87	>500

TABLE 4. GREASE TEST DATA (B)

Code	Oil Separation (Static) (%)	Four Ball EP LWI	Evaporation Loss (%) At 99 ºC	Dirt Count Particles per milliliter			Water Washout (%)	Evaporation Loss @ 180ºC, % (TGA)	Low Temperature Torque			
				25-75 Microns	75-125 microns	125+ microns			Test temperature, ºC	Breakaway (N.m)	1 min (N.m)	5 min (N.m)
G-1	16.5	23	0.88	500	200	100	5.63	41.2	-54	4.93	1.9	1.63
G-2	3.0	53	0.23	650	100	0	1.53	3.6	-40	2.47	1.27	0.93
G-3	0.3	28	0.26	350	100	50	1.46	1.3	-40	2.18	1.4	1.12
G-4	1.4	29	0.46	350	50	0	2.31	1.3	-54	0.86	0.43	0.4
G-5	0.9	22	0.14	50	0	0	1.00	0.4	-40	5.85	1.97	1.64
G-6	0.6	66	0.35	100	0	0	2.67	2.4	-54	3.98	1.83	1.46
G-7	6.1	68	0.60	250	50	0	1.69	5.2	-54	0.82	0.53	0.47
G-8	0.5	25	0.06	100	50	0	2.97	2.6	-40	2.79	1.72	1.59
G-9	0.9	39	0.19	50	0	0	2.16	3.6	-40	0.9	0.43	0.39
G-10	5.3	39	0.20	0	0	0	5.40	2.6	-54	1.92	1.22	1.09
G-11	0.01	38	0.10	0	0	0	0.61	2.3	-20	2.67	1.61	1.41
G-12	2.6	39	0.53	400	0	0	1.47	6.4	-54	0.74	0.52	0.5
G-13	0.0	20	0.26	100	0	0	3.19	2.0	-54	2.34	1.53	1.19
G-14	0.8	20	0.36	0	0	0	2.43	2.5	-54	2.56	1.47	1.16
G-15	10.3	25	0.35	100	0	0	9.64	2.4	-54	7.1	3.29	2.99
G-16	10.8	20	0.22	100	50	0	6.83	2.1	-54	0.95	0.55	0.49
G-17	5.3	26	0.18	100	0	0	5.49	0.2	-54	36.0	3.48	3.2
G-18	17.1	39	0.58	150	50	0	8.68	11.7	-54	0.91	0.47	0.36
G-19	0.01	21	0.31	0	0	0	0.95	2.0	-40	2.67	1.67	1.47
G-20	7.6	25	0.22	0	0	0	1.51	5.0	-54	0.98	0.5	0.43
G-21	0.5	36	0.10	50	0	0	0.30	1.9	-40	1.27	0.71	0.56
G-22	9.9	39	0.14	400	0	0	0.79	1.8	-54	1.46	1.12	1.01
G-23	10.8	57	0.62	300	0	0	1.24	8.5	-54	1.05	0.54	0.45
G-24	2.0	34	2.10	100	0	0	3.18	6.5	-54	3.51	2.54	1.96
G-25	1.6	26	0.17	0	0	0	3.24	1.1	-40	1.73	1.22	0.87
G-26	0.1	21	0.24	0	0	0	1.42	1.1	-40	2.74	1.97	1.58
G-27	1.7	54	0.06	50	0	0	-	0.2	-40	11.0	5.6	4.77
G-28	4.2	38	0.05	0	0	0	-	1.1	-40	3.88	2.29	2.07
G-29	1.8	67	0.05	0	0	0	-	0.3	-40	5.96	3.67	3.54
G-30	0.8	144	0.03	0	0	0	-	0.1	-40	23.6	9.6	7.32
G-31	3.8	58	0.03	100	0	0	-	0.1	-54	0.8	0.54	0.52
G-32	2.5	44	0.02	0	0	0	-	0.2	-40	11.55	5.09	4.37
G-33	3.1	56	0.08	50	0	0	-	1.5	-40	14.15	5.31	4.87
G-34	0.1	26	0.29	100	0	0	-	3.9	-54	1.37	0.78	0.64
G-35	6.1	135	0.45	0	0	0	-	5.2	-54	1.66	0.58	0.5
G-36	0.3	22	0.17	0	0	0	-	1.2	-40	1.33	0.65	0.57
G-37	1.9	62	0.0	50	50	0	-	0.1	-54	0.99	0.59	0.47
G-38	1.2	84	0.05	200	0	0	-	0.1	-54	0.96	0.6	0.53

TABLE 5. GREASE TEST DATA (C)

Code	Channeling Ability (Torque Test)	Apparent Dynamic Viscosity Poise, @25C, $25s^{-1}$	Rolling Bearing Noise	Oxidation Stability (PDSC) @180 ºC, min	Base Oil Kinematic Viscosity (cSt)	
					40 °C	100 °C
G-1	No	223	noisy	9.3	13.92	2.90
G-2	Yes	580	very noisy	32.0	23	5
G-3	Yes	770	Noisy	N[1]	72	19
G-4	Yes	294	Standard noise	N	74	25
G-5	Yes	359	very noisy	N	108	25
G-6	No	184	very noisy	637.9	31.2	6.0
G-7	No	133	very noisy	937.6	10.3	2.9
G-8	Yes	208	Quiet	2675.4	100	11
G-9	No	250	Noisy	986.4	22	5
G-10	No	450	Standard noise	48.0	24	5
G-11	No	332	noisy	2128.1	420	34
G-12	Yes	154	very noisy	938.7	10.3	2.9
G-13	Yes	500	noisy	15.2	18	4.5
G-14	Yes	485	quiet	15.9	25	6
G-15	No	384	very noisy	53.3	20	4.2
G-16	No	144	standard noise	46.8	22	4.7
G-17	Yes	218	Standard noise	13.0	61	9.7
G-18	No	238	Noisy	112.4	9.1	2.7
G-19	No	168	very noisy	445.1	100	13.7
G-20	No	273	very quiet	28.1	18	4
G-21	No	290	Quiet	43.4	30	6
G-22	No	150	very noisy	522.2	30.5	5.9
G-23	No	129	very noisy	115.7	14.5	3.6
G-24	No	635	very noisy	32	28.7	5.5
G-25	Yes	267	Standard noise	34.3	60.7	9.5
G-26	Yes	2100	Standard noise	34.9	60.7	9.5
G-27	No	238	Standard noise	N	240	26
G-28	No	191	Standard noise	N	85	11
G-29	No	206	very noisy	N	160	18
G-30	Yes	103	very noisy	N	400	37
G-31	No	65	Quiet	N		
G-32	Yes	208	very noisy	N	240	26
G-33	No	2250	Noisy	N	32	7
G-34	Yes	980	Standard noise	N	-	-
G-35	Yes	77	Noisy	N	-	-
G-36	No	307	Noisy	54.5	110	15
G-37	Yes	138	very noisy	N	150	45
G-38	No	109	very noisy	N	150	45

1. No oxidation

CONCLUSIONS

The precision bearing grease guide was successfully developed and published as ASTM F 2489-06, Standard Guide for Instrument and Precision Bearing Lubricants-Part 2 Greases. The tradenames of tested greases were listed in Research Report F-34-1000. The lubricating greases presented in this guide were commonly used in precision rolling element bearings (PREB). These greases were selected for the testing based on the grease survey obtained from DoD, OEM and grease manufactures and evaluated according to the test protocol that was designed by ASTM F-34 Tribology Subcommittee. This test protocol covered the essential requirements identified for precision bearing greases. The performance requirements of these greases are very unique. They were dictated by the performance expectations of precision bearings including high speed, low noise, extended life, and no contamination of surrounding components by the bearing's lubricant system.

To select or replace greases based on the data and properties information presented in this guide alone could be very risky due to the many other factors unique to any specific application (compatibility and environmental issues, system operating parameters and requirements, life issues, and so forth). It is strongly recommended that each user fully evaluate greases for acceptability in their specific application and under conditions duplicating the system environment as closely as possible. Grease selection should be made only after successful performances in system tests have been demonstrated.

It is also recommend that prior to replacing grease in a PREB that all of the existing grease should be removed from the bearing. Reactions may occur between incompatible greases resulting in severely degraded performance. When users have more than one type of grease in service, maintenance practices must be in place to avoid accidental mixing of greases. In addition, all fluids used specifically to prolong storage life of PREBs (preservatives) should be removed prior to lubricating the bearings. Reactions may occur which would degrade the grease.

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